ENGINEERING PLANNING DOCUMENT

NO. 29, REV. 1

ESTIMATED 1963 - 1970 CAPABILITY OF THE DEEP SPACE INSTRUMENTATION FACILITY FOR APOLLO PROJECT

EPD-29 REVISION 1 2-1-62

NOTICE:

The material contained in this revision supersedes that published in the original issue dated 7/3/61. Copies of the original issue should be destroyed or marked "VOID."

Approved:

E. Rechtin
DSIF Program Director

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

CONTENTS

3

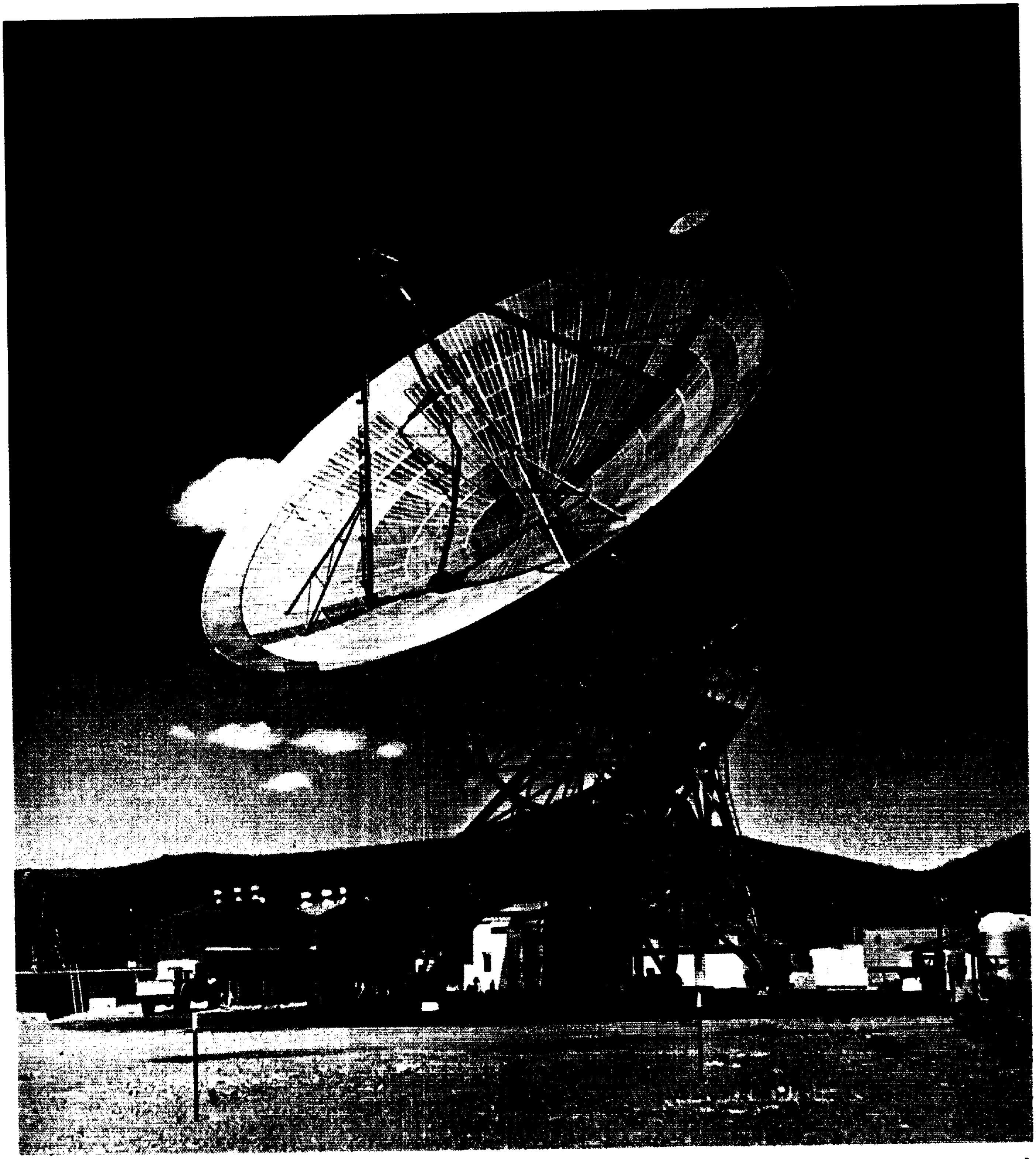
CONTENTS

(continued)

4

FIGURES

TABLES



The Deep Space Instrumentation Facility, Goldstone, California

85-ft dia Polar Mount Antenna

SECTION I

INTRODUCTION

An important requirement for the conduct of man's exploration of outer space is the establishment of a precision tracking and communications system capable of providing voice communication, telemetry, and positional tracking of the space vehicle. The Deep Space Instrumentation Facility (DSIF) has been established to satisfy this requirement in lunar and planetary programs for which the Jet Propulsion Laboratory (JPL) has been assigned either direct or supporting responsibility by the National Aeronautics and Space Administration (NASA). The DSIF is primarily intended for spacecraft tracking and communications at cislunar distances and beyond, and therefore is not designed for near Earth satellite tracking.

The DSIF is comprised of three Deep Space Stations (DSS) and, at present, a mobile station,* and the intersite communication links providing for transfer of data and for administration of operations by JPL. The DSS's are presently equipped with 85-foot-dia. reflectors, and can track at angular rates to 1 deg/sec. These large reflectors are used mainly for deep space experiments. The mobile station is equipped with a 10-foot-dia. reflector, and can track at angular rates from 10 to 20 deg/sec depending upon tracking accuracy. The mobile station is used mainly for tracking, and communication from space vehicles from injection to about 10,000 miles altitude.

The design philosophy of the DSIF is to provide a precision radio tracking system which measures two angles, radial velocity and range, and to utilize this system to send two-way communications in an efficient and reliable manner. The DSIF is scheduled to undergo long-term improvement and modernization consistent with the state of the art and spacecraft requirements. One of the basic design requirements of the DSIF is that it is possible to incorporate these improvements quickly, easily, and economically.

The National Aeronautics and Space Administration is the cognizant agency responsible for the DSIF. The Jet Propulsion Laboratory, California Institute of Technology, is under contract to NASA for the research, development, and fabrication of the DSS's and mobile stations and for the technical coordination and liaison necessary to establish and operate the DSIF throughout the world. Overseas DSS's at Woomera, Australia, and at Johannesburg, South Africa, are operated by personnel provided by cooperating agencies in the respective countries. The Goldstone station and the mobile stations are operated by United States personnel.

---

* Future use of the mobile tracking station depends upon program needs. The need for it as an acquisition aid is expected to diminish after 1963.

The Goldstone station, in addition to its participation as a member of the DSIF, is utilized for extensive research and development in space tracking and communication and for developing new equipment for the net. In most cases, the new equipment will be installed and tested at Goldstone before it is integrated into the DSIF. Once the new equipment has been accepted for general use within the DSIF, it is classed as Goldstone Duplicate Standard (GSDS) equipment, which standardizes the design and formalizes the documentation of like items throughout the net.

Operational and computational support is provided the DSIF by the Space Flight Operations Facility, SFOF, located at JPL in Pasadena, California. In addition to providing the capability for the real and nonreal time reduction of tracking and telemetry data, the SFOF will house the DSIF Control Center from which operational control of the DSIF is exercised during space flight operations.

SECTION II

STATION GEOMETRY AND COVERAGE

The three existing DSS's are spaced at approximately equal intervals of longitude around the Earth and are located as shown in Table I.

Table I. Deep Space Station Locations

DSS Location	Code	Geodetic Latitude	Geodetic Longitude
Goldstone, Calif., U.S.A.	GS	35.389°N	116.848°W
Johannesburg, South Africa	J	25.891°S	27.675°E
Woomera, Australia	W	31.382°S	136.886°E

The mobile station will, in most cases, be located so as to cover the injection point and the immediate postinjection trajectory of the spacecraft, which tend at the present time to be centered in the Southern Hemisphere. The existing DSS and mobile station installations are shown in Figures 1 through 5.

The loci of subvehicle points, with 0-degree horizon mask angles employing the 85-ft dia. polar mount (hour angle and declination coordinates) antennas at Goldstone, Johannesburg and Woomera are shown in Figure 6. This figure indicates the field of view of each polar mount DSS as a function of vehicle altitude, as well as the region of overlapping coverage. The actual ground masks and antenna pre-limits of the individual stations' polar mount antennas are shown in Figures 7 through 9. Ephemeris data may be plotted directly onto these station charts in either hour angle (HA) and declination (Dec) coordinates or in azimuth (Az) and elevation (El) coordinates. Copies of these coordinate charts are available from the Jet Propulsion Laboratory.

The DSIF is planning to construct large parabolic antennas in the range of 200 to 250 feet in diameter, and to locate one of these antennas at each DSS site. The present schedule proposes that the first large antenna be installed at Goldstone in 1965, the next at Johannesburg in 1966, and the third at Woomera in 1967. These antennas will employ altazimuth mounts (Az-El coordinates) and have approximately 7-1/2° elevation limits. The estimated coverage and station overlap employing the proposed large antennas are shown in Figure 10.

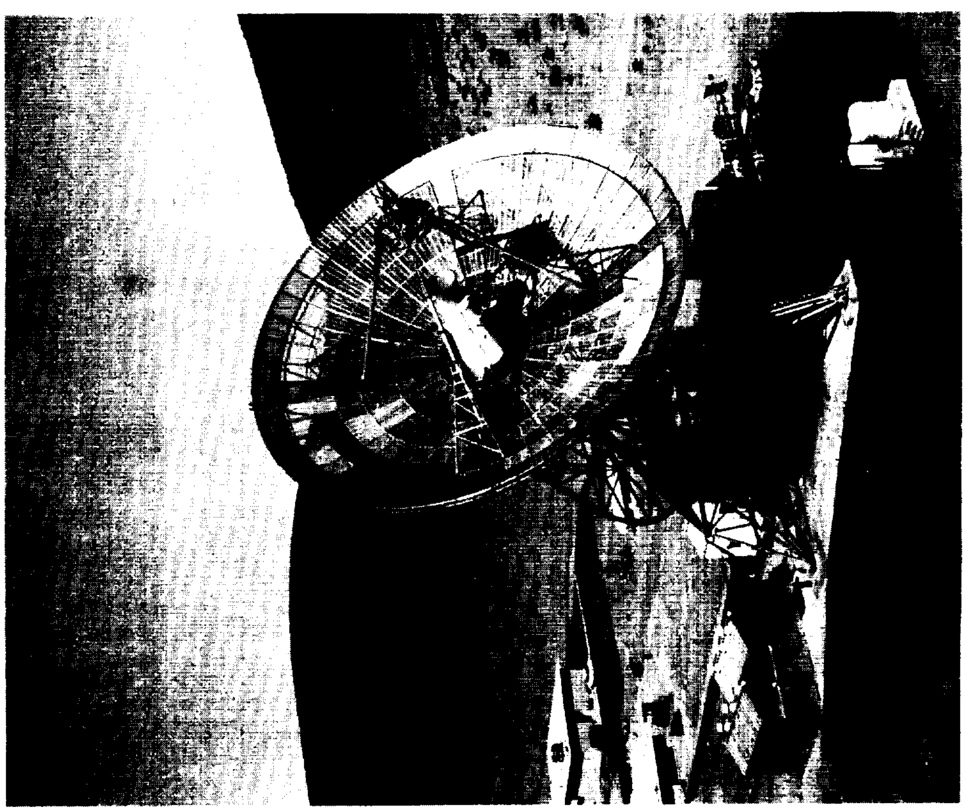


Figure 1. Goldstone, California, 85-ft dia Polar Mount (HA-Dec) Antenna

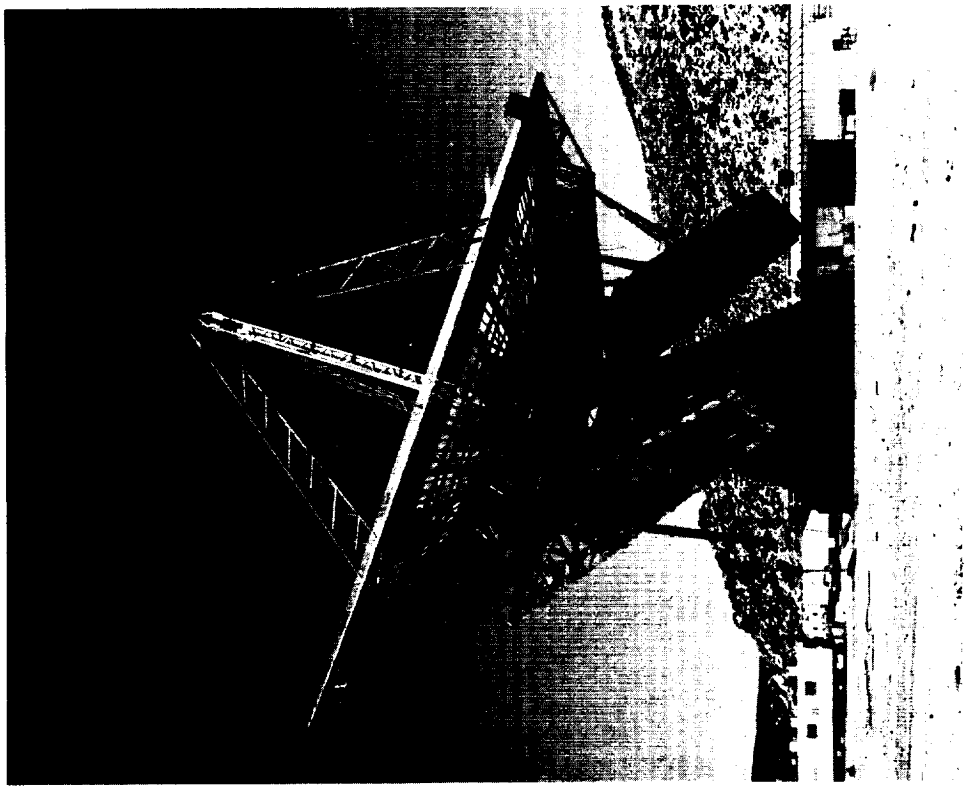


Figure 2. Goldstone, California, 85-ft dia Altazimuth Mount (Az-El) Research & Development Antenna

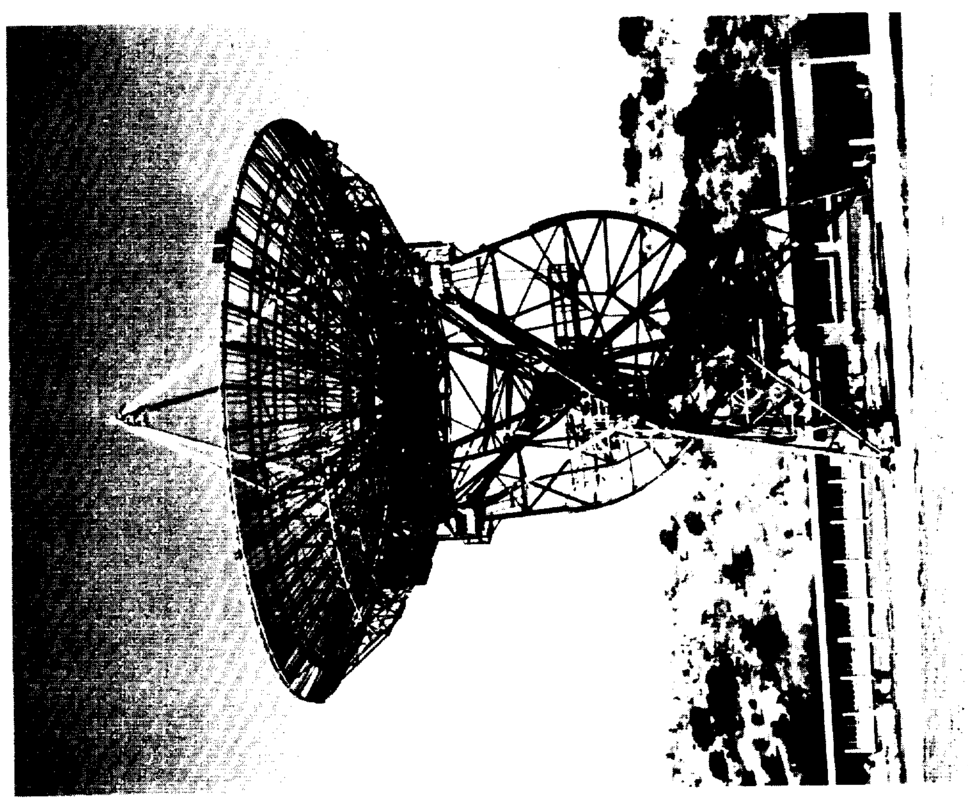


Figure 3. Johannesburg, So. Africa, 85-ft dia Polar Mount (HA-Dec) Antenna

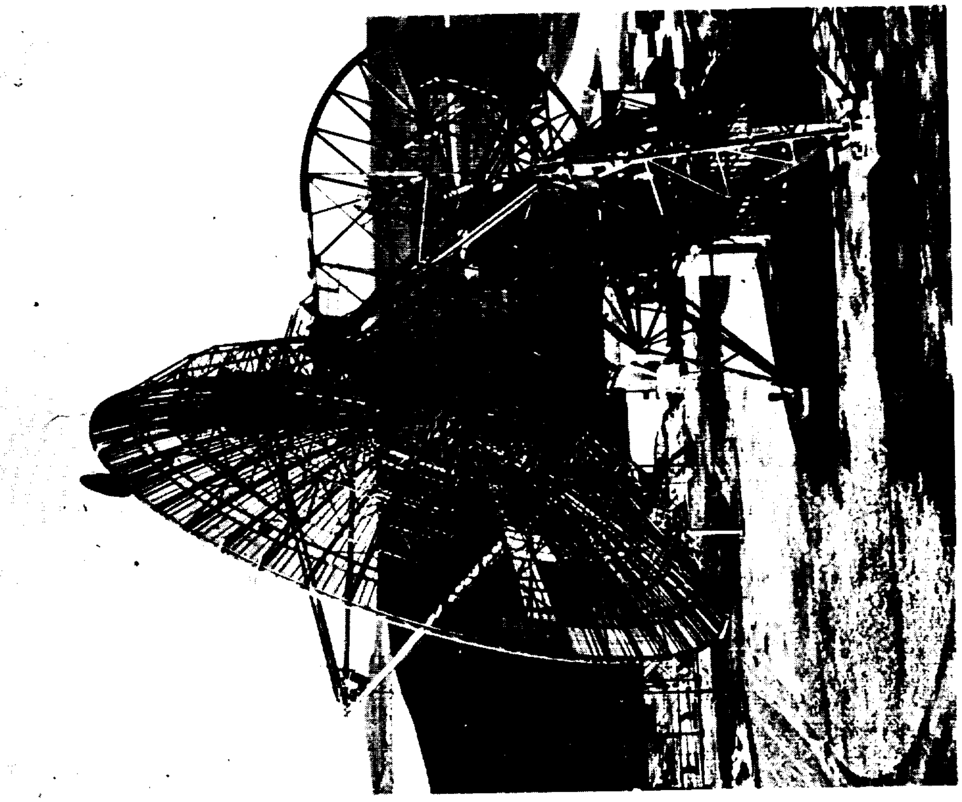


Figure 4. Woomera, Australia, 85-ft dia Polar Mount (HA-Dec) Antenna

Figure 5. Mobile Tracking Station Deployed at Johannesburg, So. Africa Site

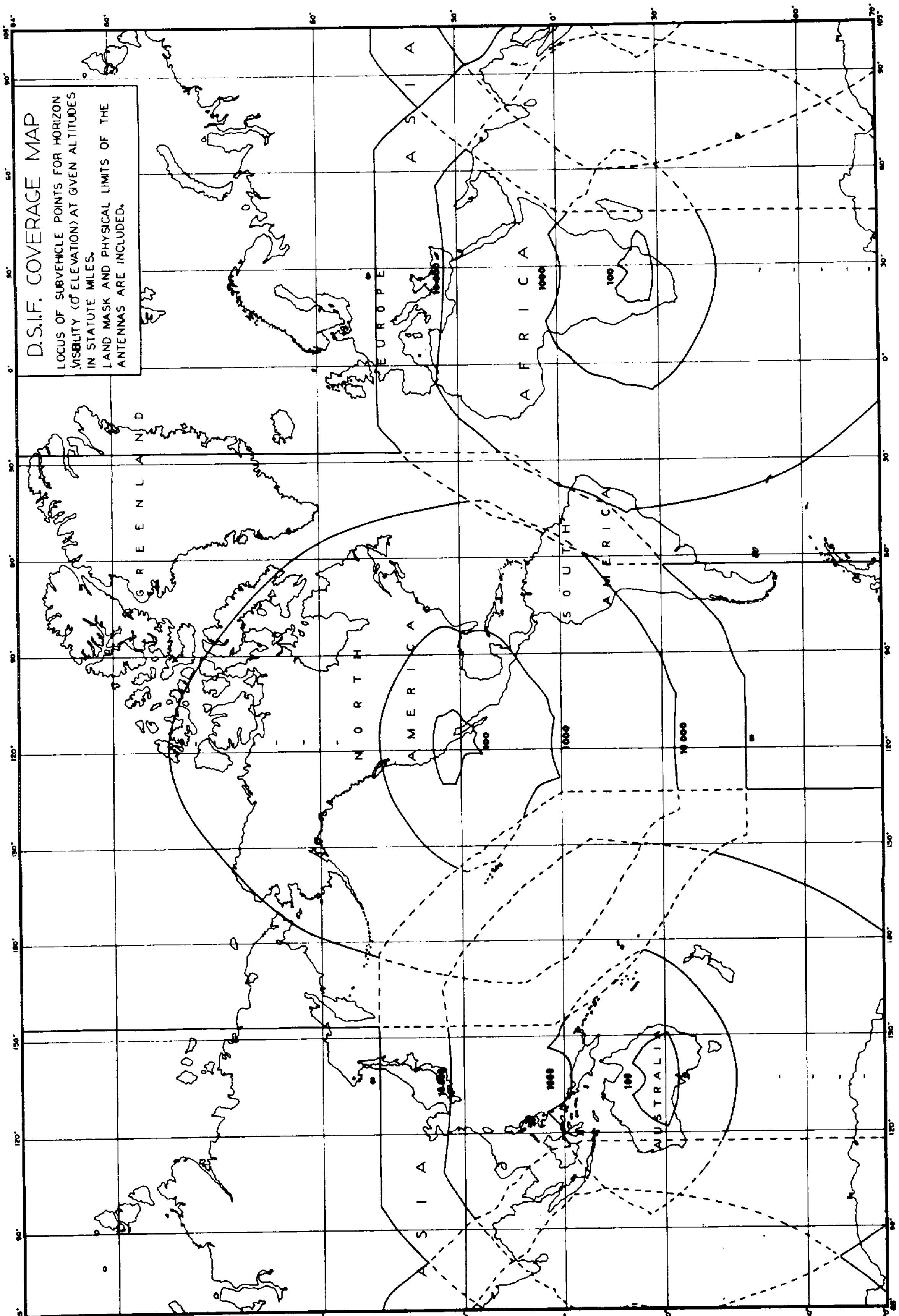


Figure 6. Station Coverage for 85-ft Polar Mount DSIF Antenna (Goldstone, Woomera, and Johannesburg)

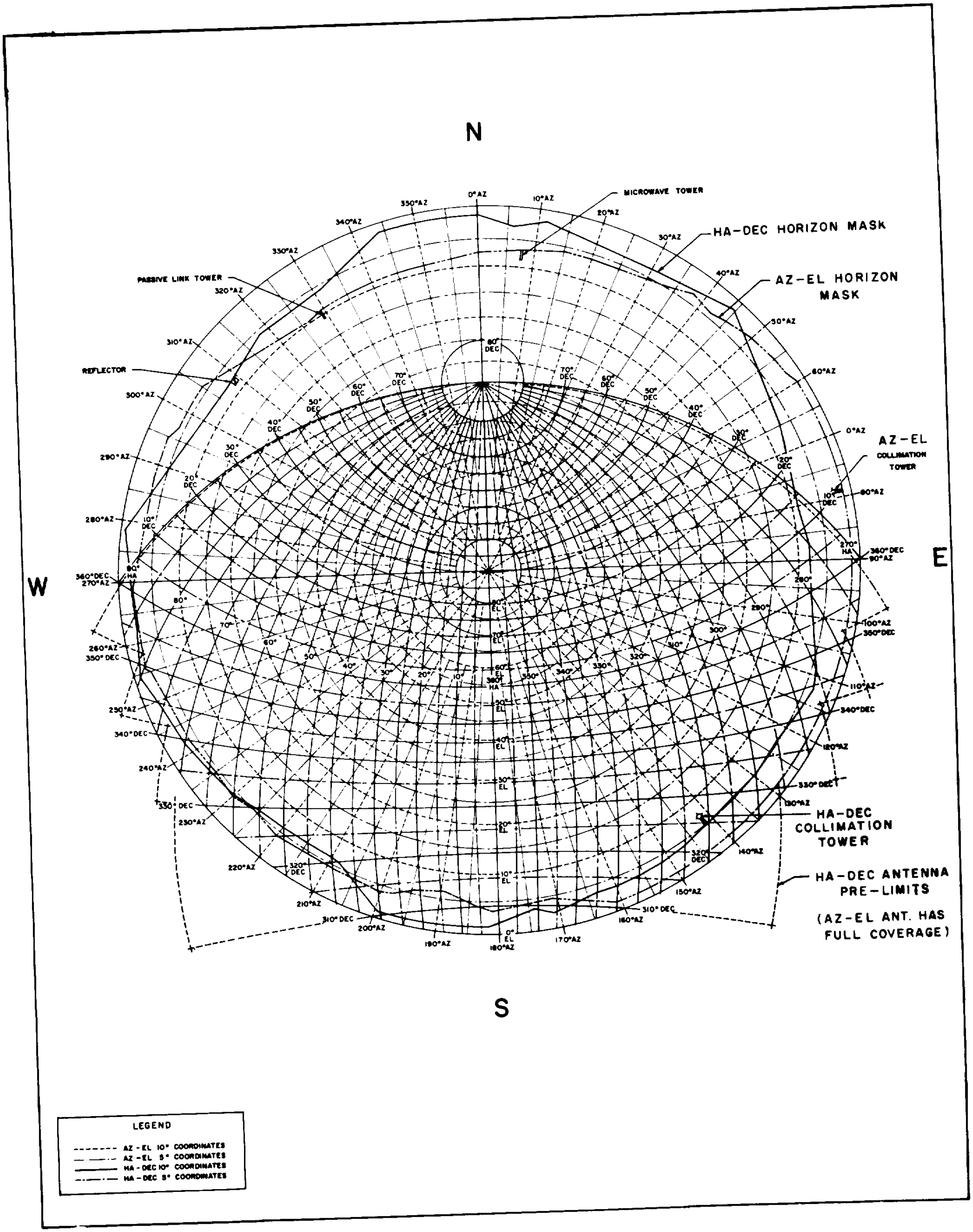


Figure 7. Goldstone Az-El and HA-Dec Coordinates Stereographic Projection for 85-ft dia Polar & Altazimuth Antennas

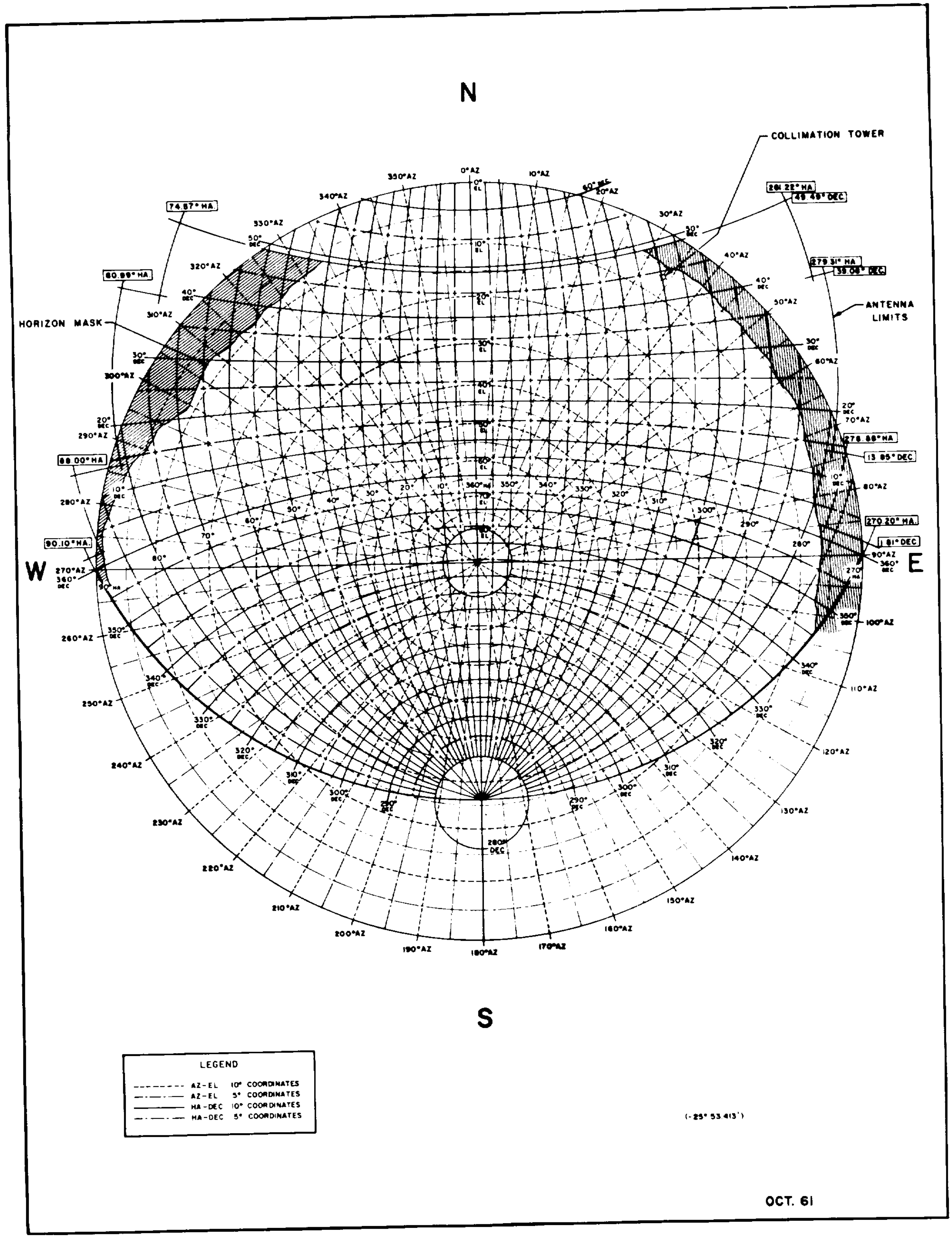


Figure 8. Johannesburg, So. Africa Az-El and HA-Dec Coordinates Stereographic Projection for 85-ft dia Polar Mount Antenna

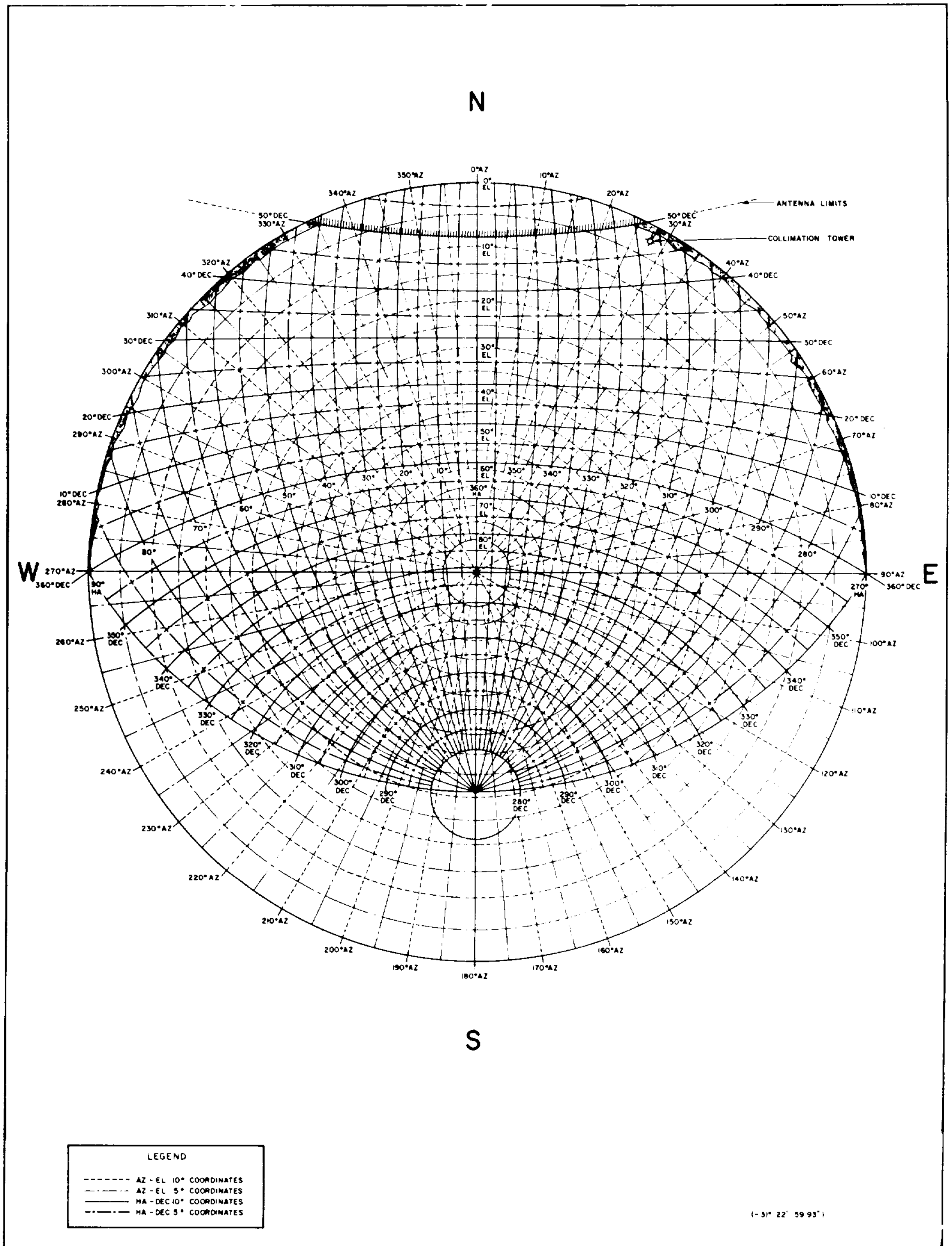
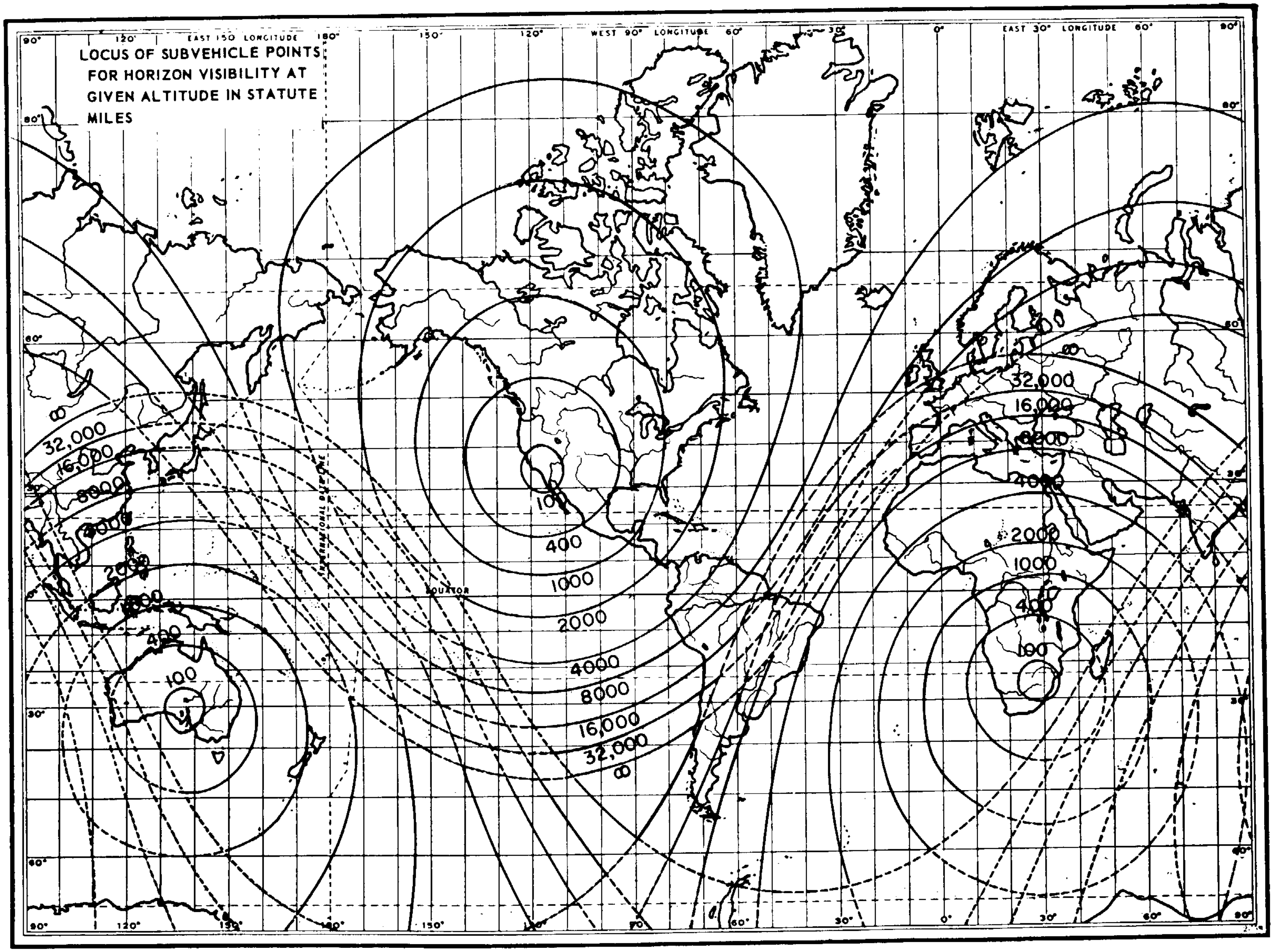


Figure 9. Woomera, Australia Az-El and HA-Dec Coordinates Stereographic Projection for 85-ft dia Polar Mount Antenna



Note: **Region of overlapping coverage are indicated by dotted lines.**

Figure 10. Station Coverage of Proposed 200-250 ft Altazimuth Mount DSIF Antennas (Goldstone, Woomera, and Johannesburg)

SECTION III

DEEP SPACE INSTRUMENTATION FACILITY SYSTEM CAPABILITIES

In the charts and text in this section, the code (I) after the year designates existing and installed facilities; (A) designates authorized and funded projects; (P) designates proposed but not yet funded projects, and (T) indicates tentatively discussed projects.

A. TRACKING CAPABILITY

1. Angle Tracking

The automatic angle tracking systems used in the DSIF are of the simultaneous lobing type. The 85-ft HA-Dec antennas (I) have two maximum tracking rate capabilities, 1.0 deg/sec and 0.03 deg/sec about each axis, depending on tracking system bandwidth requirements. During the periods in which angle tracking accuracy is most significant (e.g., when data for an initial ephemeris calculation are required), the strong signal levels available result in a root mean square (rms) angle tracking error from 0.01 to 0.02 deg. The rms tracking error at receiver threshold increases to approximately 0.05 deg. Bias errors lie in the range of -0.1 to +0.1 deg. However, optical calibration techniques such as star tracking have led to the accurate determination of the bias error as a function of angle. The bias error is removed from the observed data at the computational facility.

The 85 ft Goldstone Az-El antenna (I) will be moved during 1962 to a new location at Goldstone, Calif., where it will be used predominantly for research and development activity. When used during DSIF operations, the Az-El antenna will have tracking rates up to 2.0 deg/sec, and rms tracking errors comparable to the GSDS HA-Dec antennas.

The proposed 200-250 foot altazimuth mount DSIF antennas have the following angle tracking design goals (P). Tracking error and bias data will be determined upon completion of the first antenna installation.

Table II. Design Goals: 200-250 Foot Altazimuth Antenna

Azimuth Coverage	0 to 360 degrees
Elevation Coverage	0 to +90 degrees
Pointing Accuracy	0.02 degrees
Maximum Angular Rate	0.5 deg/sec
Maximum Acceleration	0.2 deg/sec/sec
Servo Bandwidth Adjustment	0.01 to 0.2 cps

The 10-ft Az-El mobile station antenna (I) has a maximum tracking rate capability in the range of 10-20 deg/sec. Angle errors during postinjection tracking are usually no greater than 0.1 deg rms.

Angle data from all DSIF antennas are digitally encoded directly from the antenna structure and routed to the Space Flight Operations Facility.

Most launch trajectories of outbound lunar and planetary spacecraft usually do not exceed the angular rate limitation of the 85-ft DSIF antennas. However, incoming spacecraft, especially those on a ballistic return trajectory from the Moon, can exceed the 1 deg/sec limitation of the 85-ft HA-Dec antennas or, possibly, the 10-20 deg/sec limitation of the mobile tracking station, depending upon how close the intended landing area is to the station in question and on the particular trajectory chosen.

2. Doppler

One-way and two-way doppler measurement capability is to be included at all stations in the DSIF (see Table III). Two-way doppler requires a ground transmitter in the vicinity of the DSIF receiver to achieve frequency control by a single exciter. The distance at which the DSIF stations can obtain doppler data is, of course, dependent on the sensitivity of the spacecraft receiver and the power output of the spacecraft transponder; if the carrier can be locked, doppler can be made available.

The accuracy of one-way doppler data is limited primarily because of unknown spacecraft oscillator drift. In the two-way system, the frequency control is maintained by the ground transmitter exciter and is precisely known. One-way or two-way doppler is extracted at a scaled down frequency; and this doppler frequency plus a bias frequency is multiplied in the precision doppler multiplier to a higher frequency, nearly equivalent to the doppler shift at the RF carrier frequency. A velocity measurement accuracy of ±0.2 meters/sec is anticipated employing two-way precision doppler.

Doppler frequency data are obtained by use of digital frequency counters (Eput Meters). Counting intervals are shown in Table V. Two counters provide the capability of alternate counting such that the doppler frequency is continuously measured. In the continuous count mode, the counter accumulates the total number of cycles occurring over an extended period of time to permit a measure of the change in range.

Most launch trajectories and escape velocities for outbound lunar and planetary spacecraft usually produce two-way doppler frequency rates within the DSIF receiver phase tracking capabilities. However, incoming spacecraft, particularly those on a ballistic return trajectory from the Moon, may reach relative velocities or accelerations which exceed these capabilities.

Table III. DSIF Existing and Programed Doppler Capability

Type	Year Operational DSIF			Mobile Station	Approx Accuracy (mtr/sec)
	GS	J	W		
L-Band[a]					
One-way Non-precision[c]	-	1961 (I)	1961 (I)	-	> 40
One-way Precision	1961 (I)	1962 (A)	-	1961 (I)	≈ 30
Two-way Precision	1961 (I)	1962 (A)	-	1961 (I)[d]	≈ 0.2
S-Band[b]					
One-way Precision	1963 (A)	1963 (A)	1963 (A)	1963 (P)	≈ 0.2
Two-way Precision	1963 (A)	1963 (A)	1963 (A)	1963 (P)	≈ 0.2

Notes:

a. The DSIF has been requested to vacate the present 890/960 mc/s band by mid 1963. Data listed for reference only.

b. The DSIF will be operational on 2115/2295 mc/s in mid 1963.

c. The non-precision doppler system does not contain the doppler multiplier.

d. The present 25 watt transmitter power output limits the range of the MTS to several tens of thousand miles.

3. Precision Ranging (P)

A ranging system is presently under development by JPL and is planned for operational use with a 2115/2295 mc/s transponder. The system measures the time difference between two identical, separately generated, pseudo random noise codes (one generated at the transmitter for modulation and the other at the receiver for correlation detection) to represent range. (The spacecraft transponder may or may not utilize the same correlation technique to reconstruct the code sequence before retransmission to Earth. Reconstruction is needed for ranges comparable to planetary distances.) For lunar distances a simple "turn-around" transponder can be employed

which transfers the modulation from the spacecraft receiver to its transmitter. Unambiguous ranging at interplanetary distances is planned, with a radio frequency round-trip time accuracy of 0.1 μ sec.

The standard transmitting and receiving equipment located at the DSS's will be adaptable to the ranging mode. The ranging detection system is operable as long as carrier phase coherence is maintained in the two-way system. The general mode of operation for the ranging system will be to initiate range modulation, establish range lock, and then to remove range modulation and count carrier doppler cycles to maintain the range tally.

The inclusion of precision ranging in the Apollo project plans would appreciably reduce the amount of postinjection tracking data required for trajectory calculations leading to a midcourse correction and a subsequent lunar encounter.

4. Data Handling

Automatic data handling equipment is operational at all DSIF stations. This equipment automatically punches out on paper tape, in standard Baudot teletype 5-hole code, characters which represent carriage return, line feed, figures, spaces, and the following technical information:

Station Identification
Data Condition
GMT
Antenna Hour or Azimuth Angle
Antenna Declination or Elevation Angle
Doppler Frequency
Range Data (P)
Range Correction Code (P)
Range Data Condition (P)
Day of Year

The system is capable of punching at a rate of 60 characters per second. The format is so designed that one complete set of information is printed on one line of a teletype page printer which will accept a nominal 60 characters including spaces (see Table IV). The normal maximum teletype speed is 60 words per minute or 6 characters per second for tape transmission, punching, or page printing. However, if required, the speed may be increased to 10 characters per second by installing higher speed teletype equipment. The data system sampling rates and doppler counting intervals are indicated in Table V.

Transfer of telemetry data from overseas DSS's to JPL may be accomplished in several ways, depending on the urgency of the data. The normal method is to airmail the telemetry tapes to JPL, with an attendant delay of approximately 72 hours.

Table IV. Teletype Format - with Ranging*

Station Number	Data Condition	GMT	Hour Angle	Declination	Doppler Cycle Count **	Range Code / Range Correction Code	Range Data Condition	Day of Year
2	Ø1Ø	Ø145ØØ	35977Ø	345558	Ø33268Ø	28276685718	1	3Ø1
2	Ø1Ø	Ø145Ø2	359477	345861	Ø332687	28277327Ø19	1	3Ø1
2	Ø1Ø	Ø145Ø4	359185	346163	Ø332694	28277968321	1	3Ø1
2	Ø1Ø	Ø145Ø6	358893	346646	Ø3327Ø1	282786Ø9619	1	3Ø1
2	Ø1Ø	Ø145Ø8	3586Ø1	346768	Ø3327Ø8	28279251Ø2Ø	1	3Ø1
2	Ø1Ø	Ø1451Ø	3593Ø8	347Ø71	Ø332715	28279892423	1	3Ø1
2	Ø1Ø	Ø14512	358Ø16	347373	Ø332722	2828Ø533821	Ø	3Ø1
2	Ø1Ø	Ø14514	357725	347675	Ø332729	28281175222	Ø	3Ø1
2	Ø1Ø	Ø14516	357433	347978	Ø332736	28281816623	Ø	3Ø1
2	Ø1Ø	Ø14518	357141	34828Ø	Ø332743	28282458121	Ø	3Ø1
2	Ø1Ø	Ø14520	356849	348582	Ø33275Ø	28283Ø99622	Ø	3Ø1
2	Ø1Ø	Ø14522	356557	348884	Ø332757	28283741121	Ø	3Ø1

*Word lengths may be changed via patch panel - maximum word lengths shown.

**Doppler cycle count may be expanded to 8 or 10 places.
Must be derived from same RF carrier used for range data.

Table V. Data System Sampling Rates and Doppler Counting Intervals

Sample Rates

Interval	Increments
1 - 9 sec	1 sec
10 - 90 sec	10 sec
1 - 9 min	1 min
10 - 90 min	10 min

Doppler Counting Interval

Data Condition Code	Seconds
0	1
1	5
2	10
3	20
4	30
5	40
6	50
7	60
8	Continuous count

Other more rapid methods include use of the teletype system after the completion of the particular DSS tracking mission, and use of commercial radio-telephone facilities. At the present, local processing of telemetry data is necessary when teletype or radio-telephone methods are used. If wideband communication links become available, real time transmission of selected telemetry data may be accomplished.

B. COMMUNICATIONS

1. Allocated DSIF Frequencies and Proposed New Frequencies Compatible with the DSIF

It is anticipated that other networks will provide the primary tracking and communications for the Apollo spacecraft when the latter is in the near Earth region, and that the DSIF will provide the primary tracking and communications functions when the Apollo spacecraft is above 8000 miles altitude.*

The present and proposed DSIF antenna reflectors are compatible with frequencies in the region of 400 mc/s to 2400 mc/s. To change frequency from one part of this region to another requires replacement of the antenna feed, the receiver input stages, and the transmitter. Simultaneous operation on two widely separated frequencies within the 400-2400 mc/s region requires the compatible mounting of two antenna feeds on the reflector and completely separate receivers and transmitters.

The allocated DSIF transmitter frequency region is 2115 ±5 mc/s, and the allocated receiver frequency region is 2295 ±5 mc/s. These allocations are divided within the DSIF into three transmitting and three receiving channels as shown in Table VI. These channels operate in pairs to maintain the 240/221 spacecraft transponder frequency ratio, thus permitting individual communication to and from three different spacecraft which may be operational within the same time period.

For wideband (e.g., 10 mc/s) transmissions and voice backup from the Apollo spacecraft at cislunar distances, the DSIF is recommending use of the 1705 ±5 mc/s region.

* The 8000 mile altitude is based upon having continuous DSIF tracking coverage on the Goldstone-Woomera leg (see Figure 6). This number may be unduly restrictive. Studies of the actual Apollo trajectories are expected to reduce the limiting altitude to a value more compatible with the near-Earth network. In Ranger and Surveyor flights, for example, the limiting DSIF altitude is approximately 300 miles, due to the selection of the launch orbit. For a spacecraft returning to the geographical area of the United States, the altitude would be somewhat higher than 300 miles but significantly less than 8000 miles.

Table VI. DSIF Space Mission Frequencies

Frequency mc/s	Year Operational in DSIF	Use
1705 ± 5	1964 (P)	Apollo spacecraft to Earth: Wideband transmission and two-way voice communication.
2115 ± 5: Tentative DSIF Channels 1) 2110 - 2111 13/16 2) 2111 13/16 - 2114 13/16 3) 2114 13/16 - 2120	1963 (A)	Transmitter frequencies (3-channels) for DSIF equipment. Receiver frequency (1-channel) for individual spacecraft receiver/transponder
2295 ±5: Tentative DSIF Channels 1) 2290 - 2293 1/3 2) 2293 1/3 - 2296 2/3 3) 2296 2/3 - 2300	1963 (A)	Receiver frequencies (3-channels) for DSIF equipment. Transmitter frequency (1-channel) for individual spacecraft transmitter/transponder.

Note: The transmitting and receiving frequencies of channels 1, 2, and 3 above, are in the ratio of 240/221 to be compatible with the spacecraft transponder. Channel number's 2 and 3 are compatible with the JPL precision (3 mc bandwidth) ranging system.

2. Voice Channels

Voice channels between the spacecraft and the DSIF are not presently part of the GSDS equipment at the sites. However, voice channels can be easily added. The major restriction to the addition of voice channels in the 2115/2295 mc/s bands is that such addition must not limit either the spacecraft or DSIF receiver's ability to maintain phase lock on the RF carrier. The detection capability of the DSIF system depends on maintaining this phase lock.

3. Telemetry

The ground telemetering system provides information bandwidths of 1 to 3 mc/s detection capability, and is part of the 2295-mc/s receiver. In most instances, the method of subcarrier detection and the logical design of the ground station telemetering system will be dictated by the requirements of a particular mission, and will most likely vary somewhat from project to project. As a standard capability, however, IRIG subcarrier channels 1 through 8 are presently incorporated in the DSIF. Phase-lock subcarrier detection techniques are utilized.

4. Television

Considerable experience in handling real time television from the Moon via the DSIF will be gained through the Ranger and Surveyor projects. An illustrative design for Apollo appears in Appendix A.

5. Command Capability

To provide for the possible interrogation or command of a space vehicle, a digital command system will be introduced to the DSIF in 1962. Again, as in telemetering, command capability is closely related to the requirements of the individual mission or project, and in most instances the command-unit/DSIF interface will be at the transmitter phase-modulator.

6. Recording Equipment

The recording equipment installed or programed for installation at each DSIF site is designed to allow recording of a variety of signals from spacecraft and local sources. The types of available equipment are shown in Table VII. Signal-conditioning equipment of various types is also provided.

Oscillograph recorders are used primarily for local system evaluation and quick-look data. For permanent data records, the magnetic tape recorders are used. The Ampex FR-100, FR-600, and the CEC-752 are used for low frequency data recording. All these recorders are capable of operating at speeds from 1-7/8 inches/second to 60 inches/second and the frequency response is consistent with the manufacturer's specifications.

The Ampex FR-700 tape recorder is used for high frequency data recording as required. Signal conditioning equipment provides the capability of recording data directly from the receiver IF amplifiers prior to detection, with a bandwidth of 3-1/3 mc/s.

In addition to the recording capability shown in Table VII, a digital system is planned for recording station evaluation data and other data on magnetic tape in suitable format for direct entry into an IBM 7090 computer. This system will have the capability of taking analog or digital data and processing it for recording on a digital tape recorder.

The timing system available at each site is stable over a one-day period to 5 parts in 10^{10}. Local time readout is synchronized to WWV or WWVH to at least 10 milliseconds. Synchronization to WWVL or NBA to at least 1 millisecond is planned during the 1962-1963 period. Time readout is available locally in digital and visual display, and serial coded time is available at 1-sec, 1-min, or 1-hr readout intervals. Atomic timing and frequency control systems are under consideration for installation in the DSIF in the 1963-1964 period.

7. Special-Purpose Equipment

The major part of the DSIF equipment is or will be standardized for the purpose of reducing the cost of spares, ensuring equalized high performance, and allowing

Table VII. DSIF Programmed Recording Equipment as of June, 1961

Location	Direct Writing 8-Chan. Sanborn	Photog. Oscill. 14-Chan Midwest 621	Photog Oscill. 36-Chan Midwest 603 (or equiv.)	Tape Record. CEC 752-A	Tape Record. Ampex FR-107	Tape Record. Ampex FR-600 Series	Tape Record. Ampex FR-700 Series	Available Phase Locked Discriminators (Installed prior to 1961)
Goldstone (Echo Site)	Mod. 358 Prior to 1961 (I)		Prior to 1961 (I)		Prior to 1961 (I)	May '61 (I)	Oct. '62 (A)	9 units
Goldstone (Pioneer Site)	Mod. 158 Prior to 1961 (I)	Prior to 1961 (I)	Jan '62[a] (A)		Prior to 1961 (I)	Jul '61 (I)		6 units
Woomera		Prior to 1961 (I)	1963 (P)	Prior to 1961 2 units (I)			Oct. '62 (A)	6 units
Johannesburg		Apr '61 (I)	Jan '62[a] (A)	Apr '61 2 units (I)			Oct '62 (A)	9 units
Mob. Sta	Mod. 158 Prior to 1961 (I)		Prior to 1961 (I)		Prior to 1961 2 units (I)			9 units

NOTES: a - Replaces Midwest No. 621 Oscillograph previously installed.

standard training, maintenance, checkout, and countdown procedure to be utilized. Such standardized equipment, qualified for use in the DSIF, is designated as Goldstone Duplicate Standard (GSDS).

In general, special-purpose communications equipment is limited to modulation, demodulation, voice communications, and data-handling equipment specifically required to satisfy a particular program need. Funding and engineering of this special-purpose equipment is handled as part of, and is the responsibility of, the program using it; however, spares requirements, interface configurations, operational procedures, etc., must be coordinated through the DSIF. Facility negotiations and schedules are the responsibility of the DSIF. Operation of specialized equipment is decided by mutual agreement.

8. Intersite Communications

A NASA-operated full duplex teletype (TTY-FD) communications net presently exists which links the Goldstone, Woomera, and Johannesburg DSS's to the JPL Space Flight Operations Facility. Commercial voice circuits (CV) between the DSS's and the Space Flight Operations Facility are also available. The primary function of these TTY-FD and CV circuits is to transmit tracking data (see Table IV) and to permit operational control of the DSIF net. The existing intersite communications network is shown in bold relief in Figure 11. The light relief lines of Figure 11 represent the proposed additional DSIF circuits for support of Project Apollo.

a. Voice Circuits

Leased duplex telephone lines are proposed to link the Apollo Command Center to the voice channel modulators and demodulators at each DSIF site. It is proposed that these lines follow the routing indicated in Figure 11 in order that the lines may be employed for operational messages and data transmission during periods when the station does not have spacecraft visibility. The audio bandwidth of the added telephone circuits should be sufficient to provide good quality speech transmission and possibly the delayed retransmission of telemetry data.

b. Teletype Circuits

At the present time two TTY-FD circuits between Woomera and JPL and two TTY-FD circuits between Johannesburg and JPL exist. One circuit from each overseas DSS is for a local minitrack station and the other circuit is for the DSIF station. In addition, three half-duplex TTY lines exist between Goldstone and JPL. With additional DSIF antennas being proposed for each of the DSIF sites, additional TTY-FD circuits may be added.

c. Goldstone to JPL Microwave Link

A microwave link between Goldstone and the Space Flight Operations Facility at JPL, Pasadena, California, will be operational in April 1963. The link will be capable of transmitting real time telemetry, tracking, and video data from Goldstone to JPL.

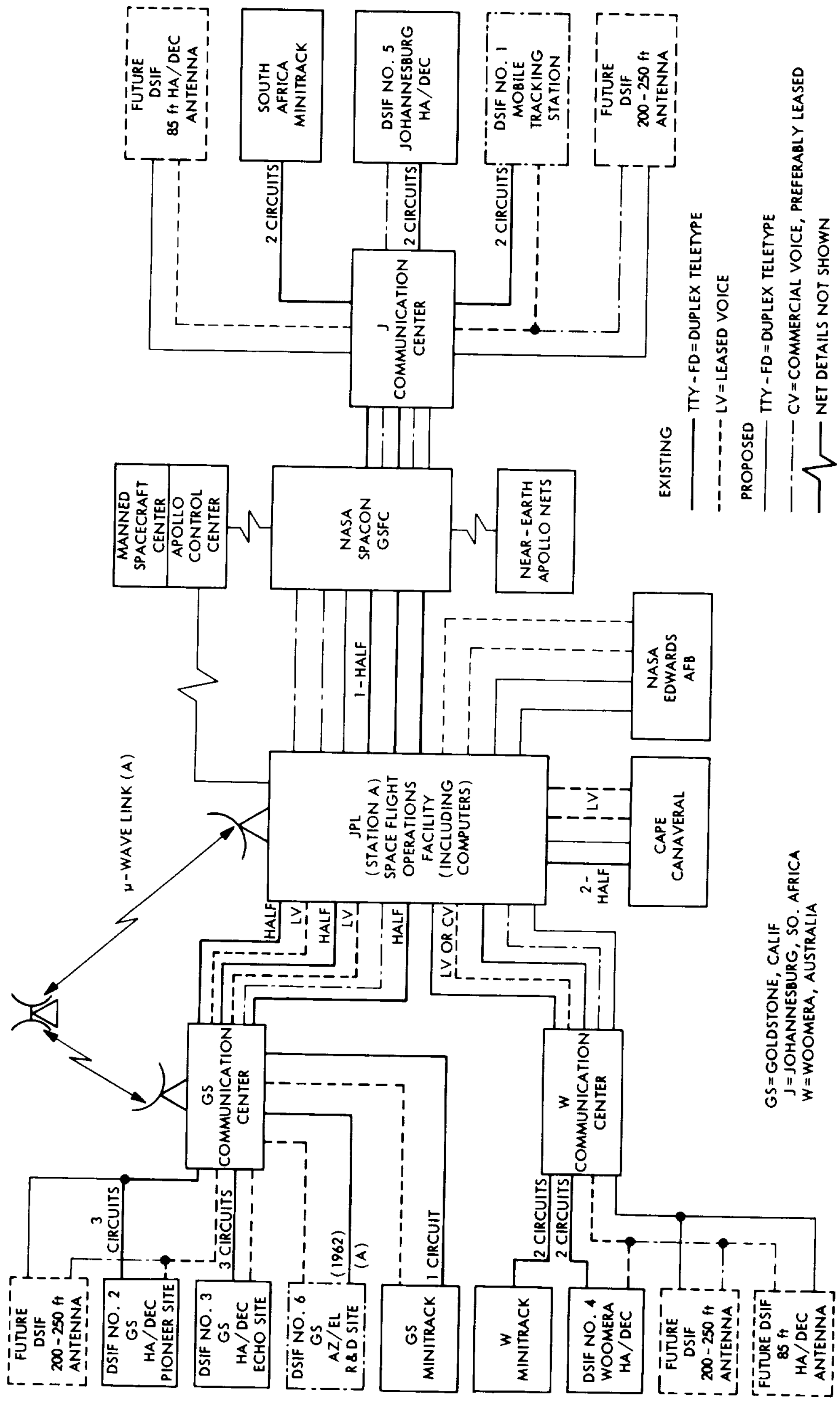


Fig. 11. Existing and Proposed DSIF World Teletype and Voice Communications Net for Project Apollo

C. DSIF SUB-SYSTEM CHARACTERISTICS

1. Existing and Proposed Antenna Reflectors and Feeds

a. Antenna Temperature

Figure 12 shows antenna temperature contours vs pointing angles recorded with the Goldstone 85-ft polar antenna at 960 mc/s, using the sum channel output of a circularly polarized, simultaneous lobing tracking feed. With a parametric preamplifier, the system excess noise temperature is about 220° K at 960 mc/s. It is planned to have temperature profiles for all DSIF stations at 2295 mc/s available late in 1963. For estimating purposes, a system excess noise temperature of 330° K can be used for 2295 mc/s. This figure includes the Moon, antenna, feed line, and parametric preamplifier temperatures.

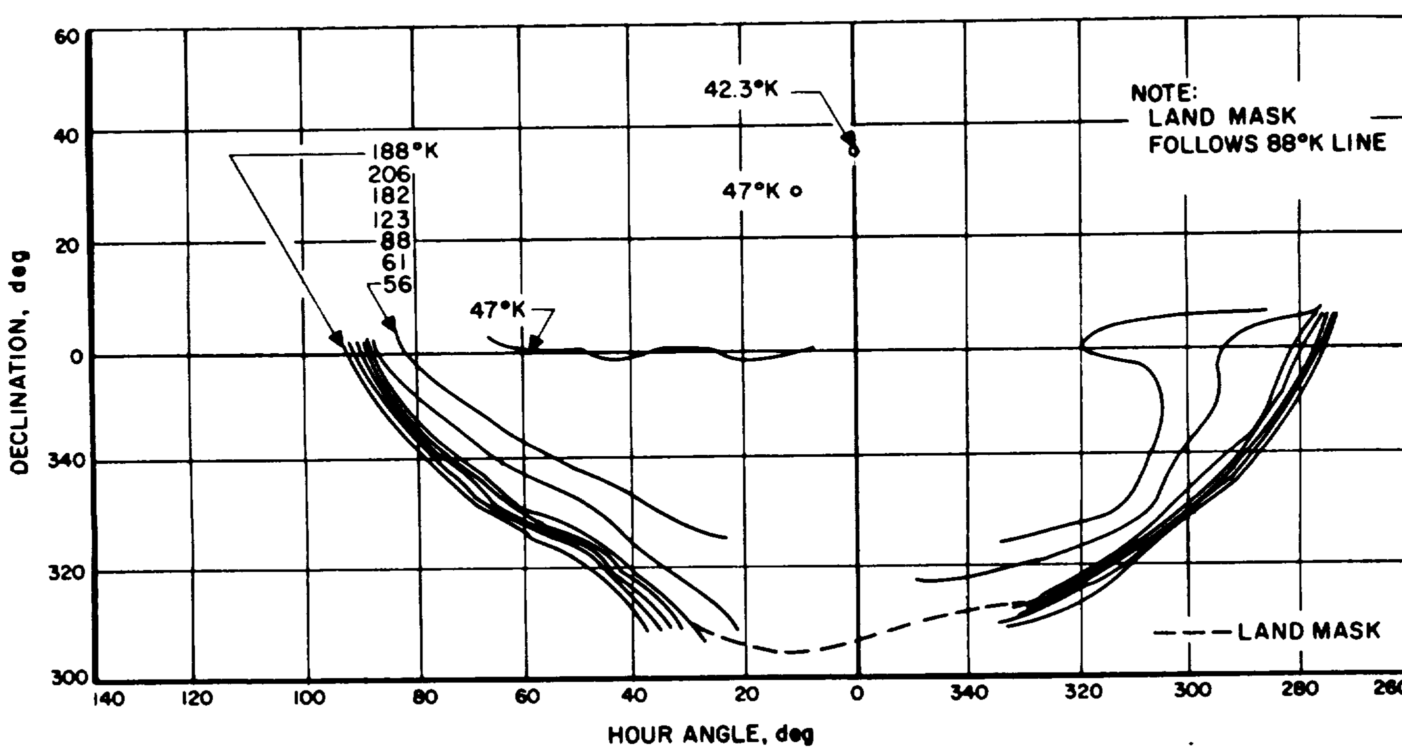


Figure 12. Goldstone Antenna-Temperature Contours vs Pointing Angles Recorded with the 85-ft Polar Antenna at 960 mc/s

b. DSIF Antenna Reflectors

The existing and proposed antenna reflectors are shown in Table VIII.

c. DSIF Antenna Feeds

The antenna feeds listed in Table IX are planned for specific program support. As a general rule, tracking and transmitter feeds are right-hand circularly polarized. Tracking feeds utilized are exclusively of the simultaneous lobing type.

2. GSDS Transmitters

Transmitter capability is incorporated in the DSIF for the purpose of providing two-way doppler data, and for command of the spacecraft. Depending on the particular mission, power outputs from 25 w to 100 kw are planned. In general, the transmitters will have a phase-modulation capability and will be excited with a voltage-controlled oscillator operated in the high-frequency region. In most instances, diplexed operation, with a receiver operating at a different frequency, will be employed. Table X indicates the present and planned future transmitter capability.

3. GSDS Receivers

The DSIF stations incorporate extremely sensitive and stable receivers which are designed to track the phase of the received RF carrier, and to detect both amplitude and phase modulation. The various receivers listed in Table XI consist of low-noise preselector/mixers, carrier and side-band IF amplifiers, detectors, and a voltage-controlled local oscillator, the combination comprising a double superheterodyne, automatic phase control receiver. Doppler data are derived from the local oscillator signal, telemetry data from a separate detection channel, and angle data from separate angle-error detection channels.

4. Typical DSIF RF System

A typical DSIF RF system embodying all of the capabilities discussed above appears in Figure 13.

5. DSIF Acquisition Procedures

The DSIF/spacecraft acquisition requirements can be separated into the following coordinates: two angles, frequency, range code, and telemetry subcarriers. Each coordinate acquisition has certain minimum time requirements which establish the shortest time in which it is possible to make a complete DSIF acquisition of the spacecraft.

Table VIII. DSIF Programmed Antenna Reflectors

Diameter feet	Type	Pointing[b] Accuracy degrees	Max. Angular Rate deg/sec	Year Operational in DSIF - CY			
				Mobile Station	GS	W	J
10	Az/El	0.05	10 – 20	1960 (I)	-	-	-
85	HA/Dec	0.01 – 0.02	1	-	1960 (I) 1962(A)	1960 (I) 1963 (P)	1961 (I) 1963 (P)
85	Az/El[c]	0.01 – 0.02	2.0	-	1960 (I)	-	-
200-250	Az/El	0.02[a]	0.5[a]	-	1965 (P)	1967 (P)	1966 (P)

[a]Design goal

[b]The capability of pointing the radio beam in a specified direction within a specified r. m. s. error is defined as the pointing accuracy

[c]Predominantly for R & D activity.

Table IX. DSIF Programmed Feed Capability

Frequency Mc	Output power	Type	Gain[a]	Reflector diameter ft	Feed-line loss db[b]	Est. noise °K[c]	Polarization	Approx. beam-width deg	Year operational in DSIF - CY			
									Mobile station	GS	W	J
1705 ± 5[f]		Listen[g]	32	10	0.5		Right Circ.	4.0	July 1964 (T)			
1705 ± 5[f]		Listen[g]	50	85	0.4		Right Circ.	0.5		Jan 1965 (T)	July 1965 (T)	July 1965 (T)
1705 ± 5[f]		Listen[g]	60	200-250	0.2		Right Circ.	0.18		Dec 1965 (T)	Dec 1967 (T)	Dec 1966 (T)
2295 ± 5 2115 ± 5	10 kw[d]	Track Trans	51.8 51	85	0.1	50	Right Circ.	0.4		Aug 1962 (A)	Jan 1963 (P)	Jan 1963 (P)
2295 ± 5 2115 ± 5	10 kw	Listen Trans	52.8 52	85	0.4	- -	Linear[e]	0.38		Aug 1962 (P)		
2295 ± 5 2115 ± 5	25 w[d]	Track Trans	33 32	10	0.5	- -	Right Circ.	3.0	June 1963 (T)			
2115 ± 5	100 kw	Trans	51	85	0.4	- -	Right Circ.	0.4		Jan 1964 (P)		
						- -						
2295 ± 5	- -	Track	61	200-250	0.1	15	Right Circ.	0.15		Dec 1965 (P)	Dec 1967 (P)	Dec 1966 (P)

[a]Gain is in decibels above isotropic radiator of matching polarization. Dual frequency, circularly polarized feeds may have as much as 6-db ellipticity at the transmitting frequency and as much as 3-db ellipticity at the receiving frequency.

[b]Indicated loss is included in antenna gain.

[c]Includes excess noise due to losses in feed lines and antenna temperature at zenith with 0°K sky temperature.

[d]Diplexer. Diplexer loss is approximately 0.2 to 0.3 db in addition to that indicated.

[e]Rotatable.

[f]To be determined by Apollo program needs.

[g]Tracking to be done simultaneously at 2295 ± 5 mc/s.

Table X. DSIF Programmed S-Band Transmitter Capabilities

Frequency mc/s	Power Output	Associated Antenna	Year Operational in DSIF - CY			
			Mobile Station	GS	W	J
2115 ±5: Tentative DSIF Channels: 1) 2110 - 2111 13/16 2) 2111 13/16 - 2114 13/16 3) 2114 13/16 - 2120	25-200 w	10-ft. Az-El	Jan 1963 (P)	-	-	-
	10 Kw	85-ft HA-Dec	- -	1963 (A)	- 1963 (P)	- 1963 (P)
	100 Kw	85-ft Az-El[a]	-	1964 (P)	-	-
		200-250 ft. Az-El		1965 (T)[a]	-	-

[a] Predominantly for R & D activity and as a command backup for planetary distances.

Table XI. DSIF Programmed Receiver Capabilities

Frequency mc/s[a]	Receiver System Excess Noise °K	Type	Ant. Dia. ft	Bandwidth: Carrier loop noise[b] - cps	Bandwidth: Telem. Ch. Information	Bandwidth: TV max RF	Mobile Station	Year Operation in DSIF: Goldstone HA/Dec #1	Goldstone HA/Dec #2	Goldstone Az/El	Woomera HA/Dec #1	Woomera HA/Dec #2	Woomera Az/El	Johannesburg HA/Dec #1	Johannesburg HA/Dec #2	Johannesburg Az/El
1705 ± 5[d]	1000	Listen[e]	10	20 - 250		10 mc	1964(T)									
	235(T)	Listen[e]	85	3 - 250					Jan 1965 (T)		July 1965 (T)			July 1965 (T)		
	235(T)	Listen[e]	200 - 250	3 - 250						Dec 1965 (T)			Dec 1967 (T)			Dec 1966 (T)
2295 ± 5:	1000	Track	10	20 - 250	1 mc	3 1/3 mc	June 1963 (A)									
Tentative DSIF Channels 1) 2290 - 2293 1/3 2) 2293 1/3 - 2296 2/3 3) 2296 2/3 - 2300	235/50[c]	Track	85	3 - 250				June 1963 (A)	June 1963 (A)		June 1963 (A)	1963 (P)		June 1963 (A)	1963 (P)	
	20	Track	200 - 250	3 - 250						Dec 1965 (P)			Dec 1967 (P)			Dec 1966 (P)

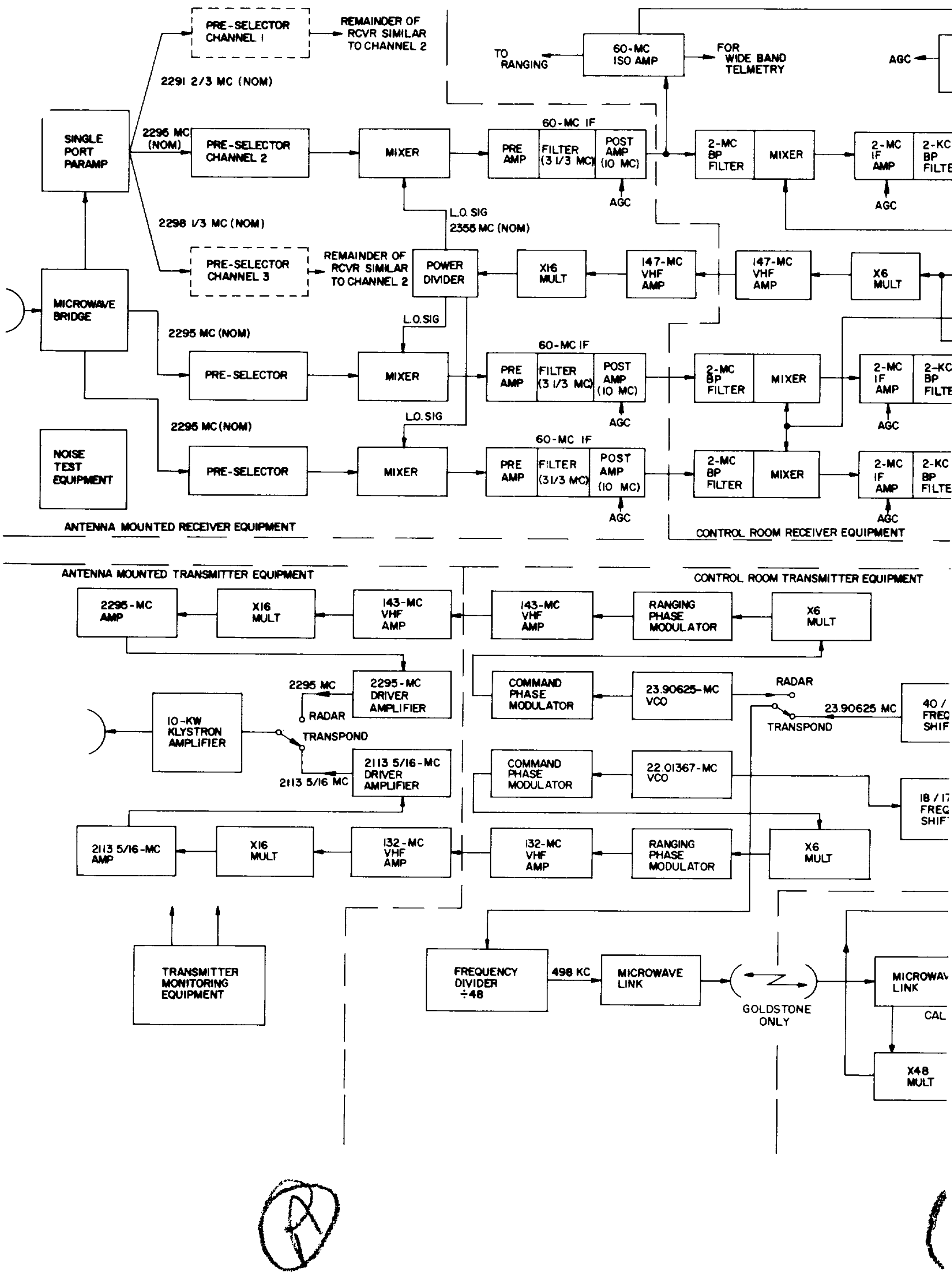
[a] In general, the receivers listed are capable of operation within several megacycles of the nominal center frequency by replacing a series of quartz crystals within the receiver system.

[b] Phase-lock loop-noise bandwidth is a function of the received signal level; hence, the frequency tracking-rate capability is a function of received signal level. The minimum bandwidths are limited because of the inherent phase instability of quartz crystals used in the communication system.

[c] A nominal 200°K excess-noise parametric amplifier will be provided for receiver No. 1 and a nominal 30°K excess-noise maser amplifier will be provided for receiver No. 2. Diplexing may increase maser system temperature to approximately 100°K.

[d] To be determined by Apollo program needs.

[e] Tracking to be done simultaneously at 2295 ± 5 mc/s.


PRE-SELECTOR CHANNEL 1
REMAINDER OF RCVR SIMILAR TO CHANNEL 2
2291 2/3 MC (NOM)
SINGLE PORT PARAMP
2295 MC (NOM)
PRE-SELECTOR CHANNEL 2
MIXER
PRE AMP
FILTER (3 1/3 MC)
POST AMP (10 MC)
60-MC IF
AGC
TO RANGING
60-MC ISO AMP
FOR WIDE BAND TELMETRY
2-MC BP FILTER
2-MC IF AMP
2-KC BP FILTE
L.O. SIG
2355 MC (NOM)
2298 1/3 MC (NOM)
PRE-SELECTOR CHANNEL 3
POWER DIVIDER
X16 MULT
147-MC VHF AMP
X6 MULT
MICROWAVE BRIDGE
2295 MC (NOM)
PRE-SELECTOR
NOISE TEST EQUIPMENT
ANTENNA MOUNTED RECEIVER EQUIPMENT
CONTROL ROOM RECEIVER EQUIPMENT
ANTENNA MOUNTED TRANSMITTER EQUIPMENT
CONTROL ROOM TRANSMITTER EQUIPMENT
2295-MC AMP
143-MC VHF AMP
RANGING PHASE MODULATOR
2295 MC
2295-MC DRIVER AMPLIFIER
RADAR
TRANSPOND
10-KW KLYSTRON AMPLIFIER
COMMAND PHASE MODULATOR
23.90625-MC VCO
23.90625 MC
40 / FREQ SHIF
2113 5/16 MC
2113 5/16-MC DRIVER AMPLIFIER
22.01367-MC VCO
18 / 17 FREQ SHIF
2113 5/16-MC AMP
132-MC VHF AMP
TRANSMITTER MONITORING EQUIPMENT
FREQUENCY DIVIDER ÷48
498 KC
MICROWAVE LINK
GOLDSTONE ONLY
CAL
X48 MULT

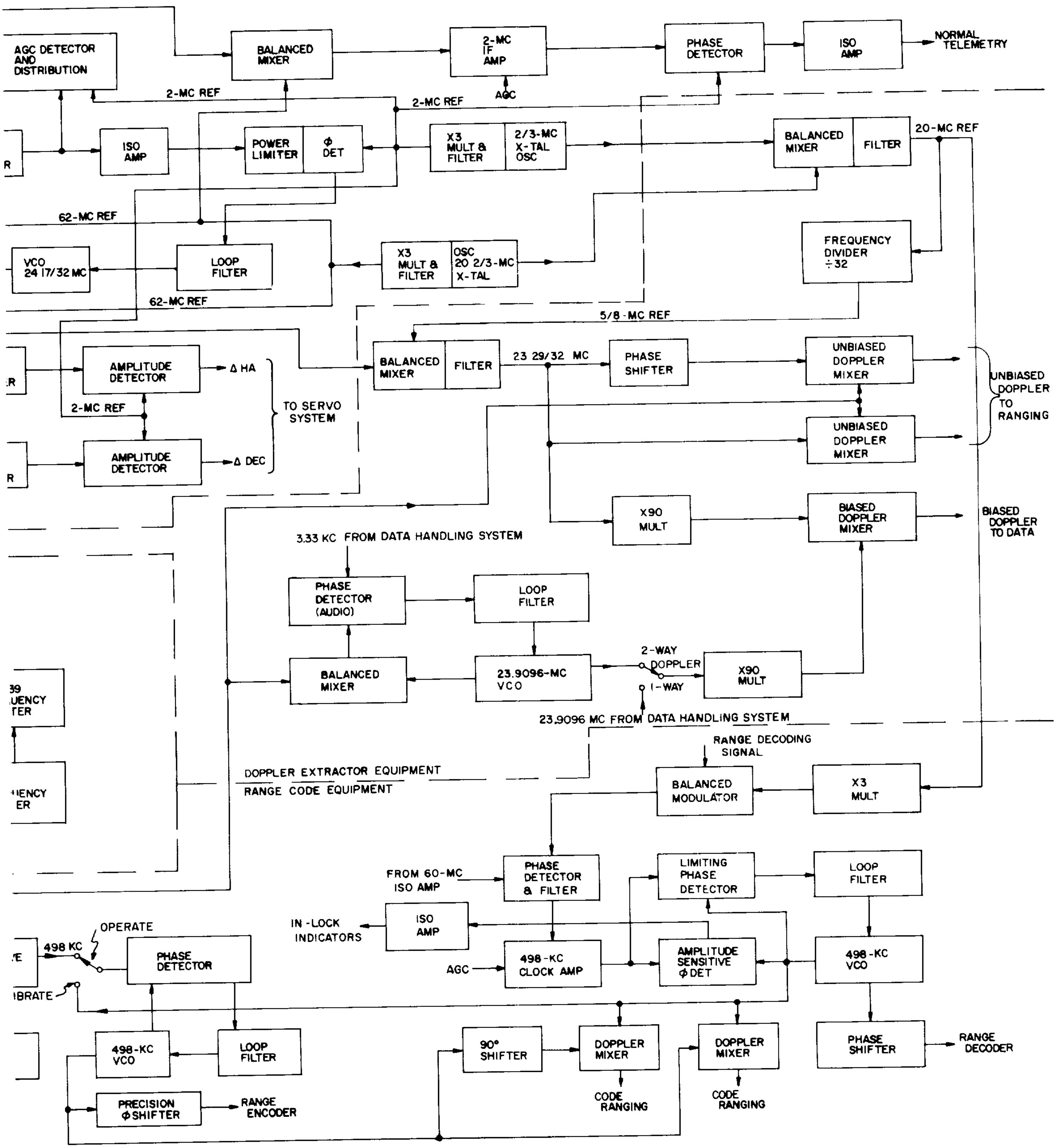


Figure 13. Goldstone S-Band RF System

a. Angle

Pointing information is usually provided for a tracking station; however, it is still necessary to search the area in which the spacecraft position is predicted. Supplied ephemeris data are usually accurate to within a degree. The search time to acquire a usable signal is less than one minute once the spacecraft appears above the station's horizon.

b. One-Way Doppler

After angle acquisition, radio-frequency lock to the spacecraft fixed frequency signal is achieved in one to two minutes at lunar distances. A priori information as to the expected received frequency considerably reduces the time required to lock to the carrier. It is usually necessary that the signal level be 3 to 6 db above the receiver threshold in order to establish carrier lock.

c. Two-Way Doppler

In this mode the spacecraft transmitter is switched from the fixed frequency exciter to a coherent variable frequency exciter whose output is an exact multiple of the signal received from the ground transmitter. Two-way radio-frequency lock is not attempted until one-way lock has been achieved, and requires an additional one to three minutes time, although by 1966 it is anticipated that automatic acquisition and lock-on equipment will be available which will shorten the time considerably.

d. Ranging

Range lock is dependent upon prior establishment of two-way doppler lock. For a ''turn-around'' ranging system, range acquisition is a matter of a few seconds at lunar distances.

e. Telemetry Subcarriers

Acquisition of the individual telemetry subcarriers requires that the RF carrier be locked in the final mode (i.e., one-way vs two-way) of operation. Thence 10 to 20 seconds per channel is required.

In practice, the time required for a DSS to achieve a complete acquisition of all the above parameters varies from two to eight minutes depending upon the desired mode of operation, the signal strength, the pointing angles, and over-all operator proficiency.

D. TESTING AND CHECKOUT

Station preparation times vary with the mission requirements. However, once the Apollo GSE is installed and operating, the stations in the net can be made operational in approximately one week. Thereafter, three hours per day are needed for routine checkout and calibration.

Currently all checkout, calibration, and testing is performed manually and considerable data reduction and interpretation are necessary before the station is judged satisfactory. However, a program is underway to automate many of the procedures now performed manually and it is estimated that the time for routine checkout will be reduced to less than one hour. Included in this automatic equipment will be go-no-go indicators, fault-locating indicators, automatic-calibration equipment, and checkout sequencers.

SECTION IV

SPACE FLIGHT OPERATIONS FACILITY

The Space Flight Operations Facility will act as a supporting element to the Deep Space Instrumentation Facility (DSIF) providing operational and data processing facilities for the reduction of tracking data and compatible video and telemetry data. The SFOF serves as the central point for the command and control of the spacecraft which are under the technical cognizance of JPL in the unmanned lunar and planetary programs.

A. SFOF CAPABILITY

The SFOF will house the DSIF Control Center and act as the communication center for the DSIF. In addition to an IBM 7090 computer, the SFOF will contain extensive analogue and digital data processing equipment. The data processing system will be capable of accepting tracking and/or telemetry data in real time directly from teletype, telephone, or microwave communication systems. The SFOF will have the capability of volume record production over the protracted periods of time typical of space flight operations.

Additional facilities and specialized display equipment will be available for the analysis and evaluation of data by cognizant technical and scientific personnel. Considerable experience in video data handling techniques will be gained in the Ranger and Surveyor programs.

The second IBM 7090 at JPL normally used for research and development programs will afford a parallel backup capability of the IBM 7090 located in the SFOF. Sufficient redundancy will exist in communications and the data processing equipment, in general, to provide the degree of reliability required for space flight operations.

B. POSSIBLE FUNCTIONS OF THE SFOF IN THE APOLLO PROJECT

1. Tracking

The SFOF, as a standard procedure, provides the necessary reduction of tracking data received from the DSIF for orbit determination, guidance, and acquisition and prediction purposes. The reduced tracking data is made available to the user of the DSIF in whatever form is convenient.

The SFOF, using the preflight standard trajectory, also provides nominal acquisition and prediction information to each DSS. During flight, post injection tracking data is used to up-date acquisition and prediction information for the DSS and other tracking stations.

2. Telemetry (including video and voice)

The extent of telemetry and the many varied possible methods of reduction require a presentation from the user prior to a detailed commitment of the SFOF in this area. The SFOF will, of course, be capable of handling telemetry compatible with Ranger and Surveyor telemetry; additionally, the SFOF is sufficiently flexible to permit rapid adaptation to the requirements of other projects. Special purpose equipments and techniques can be accommodated at the SFOF much as they are at the DSIF stations.

SECTION V

RELATIONSHIP OF THE DEEP SPACE INSTRUMENTATION FACILITY TO FOREIGN GOVERNMENTS AND OPERATING AGENCIES

The overseas stations of the Deep Space Instrumentation Facility (DSIF) exist because of agreements between the United States Government and the government of the country in which the station is located. In general, these agreements specify that the United States shall finance, construct, and install the entire facility, but that the completed station shall be staffed, operated, and maintained by the foreign government or its appointed agency. The agency in turn usually appoints a Station Manager who bears the full responsibility for the station. The Jet Propulsion Laboratory (JPL) provides a Resident Engineer who acts as the official liaison officer between the foreign operating agency and JPL. The JPL Resident Engineer has no operational authority; he merely assists the agency's Station Manager in a staff capacity.

The foregoing relationships become important when a project office or its prime contractor desire to add special support equipment and United States personnel to the overseas sites for particular missions. The support group must realize that it is a guest of the country in which the station is located, and that the project service it performs must not conflict with either the responsibility or the authority of the operating agency or its Station Manager. For this reason, any and all plans for the addition of equipment or personnel to the overseas sites must be coordinated with, and controlled by, the JPL DSIF Program Office.

SECTION VI

RELATIONSHIP OF DSIF TO APOLLO PROJECT OFFICE

As mentioned in the Introduction, the DSIF is operated by JPL under contract to NASA for the support of the latter's lunar and planetary programs. The formal relationship of the DSIF to the Apollo Project Office would be that of a supporting system element as defined by NASA Management Manual, Part I, Section 4-1-1: Planning and Implementation of NASA Projects. By this document, the Apollo Project Office would place approved functional and service requirements upon the DSIF, and the latter would employ its line organization to fulfill these requirements.

SECTION VII

DSIF INTERFACE WITH OTHER NETWORKS

A. LAUNCH PHASE

It is assumed that the Apollo spacecraft will be launched from Cape Canaveral using AMR facilities. Working relationships have been established between the DSIF and AMR covering the launch and post injection tracking of various unmanned space probes. These past relationships can form the basis of a successful future relationship for the lunar phase Project Apollo. In essence, the downrange tracking facilities of AMR maintain communications contact and track the spacecraft as long as the vehicle is within the range of the AMR equipment. The downrange tracking data is sent back to the Cape and thence to a central computer which determines the vehicle's initial trajectory. Prediction data in the form of pointing angles, etc., are sent to the DSIF Operations Center for distribution to the individual DSS's. The time sequence of the above process makes prediction data marginally available for the first pass over the Johannesburg, South Africa, DSIF station. For this reason the DSIF Mobile Tracking Station is usually deployed to the Johannesburg site to search the planned launch corridor and make the first DSIF acquisition of the spacecraft. Once the mobile station has acquired the vehicle, the Johannesburg 85-ft antenna is directed to the spacecraft and the latter's signal acquired. Tracking data from both the mobile station and the Johannesburg DSS are teletyped back to the JPL Space Flight Operations Facility.

During the near-Earth Apollo missions the prime tracking responsibility after launch is assumed to lie with other networks.

B. RETURN AND RE-ENTRY PHASE

During the return voyage of the Apollo spacecraft from cislunar space, the DSIF can provide continuous communications and tracking surveillance down to an altitude limited by the visibility and tracking rates of the return orbit (as discussed in Section III, paragraph B).

SECTION VIII

DSIF INTERFACE WITH CONTRACTOR SUPPLIED EQUIPMENT

A. GENERAL

It is required that the design of all ground support equipment (GSE) be compatible (electrically, mechanically, functionally, and operationally) with the DSIF as defined in this document and DSIF Specification No. 8907, "General Requirements for DSIF Electronic Equipment," to the extent applicable. Addition of any GSE to the DSIF ground network shall not interfere in any way with the normal operation of the DSIF, and shall be of the quick connect and disconnect variety wherever possible.

B. INTERFACE REQUIREMENTS

1. Contractor Supplied Equipment

All contractor supplied GSE, including any special purpose equipment (Section III, B-7), must be compatible with the GSDS equipment existing at the DSS's, and must operate in the environments existing at these sites. To facilitate the compatibility of contractor supplied GSE, the DSIF has prepared the specifications listed in Section IX: Reference Documents. These specifications are applicable to the contractor furnished equipment unless otherwise noted. However, the referencing of these specifications does not absolve the contractor of his responsibility to meet the above general compatibility statement of Section VIII, A; or his responsibility to insure that his equipment will perform in a satisfactory manner during the missions for which it was designed.

2. Isolation Requirements

All contractor furnished equipment must provide sufficient isolation so that its addition to the DSS shall not adversely affect the performance of the GSDS equipment at the DSS. This statement is applicable to both the contractor furnished equipment and the interconnections between the GSE and GSDS equipment.

3. Location of Interface Adaption Kit(s)

The adaption kits installed to facilitate compatibility of the GSE with the GSDS DSIF equipment shall be physically installed in as near optimum a location as possible consistent with available space and ease of installation.

4. Contractor Responsibility

In furnishing GSE to a DSS, the contractor is responsible for its proper installation, checkout, maintenance, and preflight operation. The contractor is also responsible for instruction of DSIF personnel in the proper operation and maintenance of the supplied GSE (operating personnel for the prelaunch and flight phases of the mission are usually furnished by the DSS, though exceptions can be made). Since the facilities of the DSS are scaled to the operation and maintenance of only the GSDS equipment, the contractor shall supply the equipment he needs for his personnel to install, check out, and maintain the GSE. This includes tools, test equipment and spares (other than operational spares specified below). In addition, he shall arrange for the personal needs of his employees which shall include offsite living quarters (and per diem), transportation, supplies, etc. Under emergency conditions contractor personnel will have access to station facilities and services, but due to the limited nature of the station's capabilities these cannot be arranged on a continuing basis.

5. Operating Spares

One set of operating spares shall be supplied with each set of GSE furnished the DSIF. The type and quantity of these spares shall follow the DSIF "Spares and Standards Philosophy" contained in Section X of this document. The operating spares shall be located at the same DSS site that receives the GSE. Suitable housing for these spares will be provided by the DSS, but the spares shall remain under the issuance control of the contractor for the period he is responsible for the GSE.

SECTION IX

REFERENCE DOCUMENTS

A. SPECIFICATIONS (Jet Propulsion Laboratory)

The following specifications are listed for reference by potential DSIF equipment suppliers:

8907	General Requirements for DSIF Electronic Equipment
8900	Environmental Specification, DSIF Ground Equipment, Assembly Level Test Requirements
8902	DSIF General Specification, Documentation Requirements
8905	Preferred Parts Lists for DSIF Equipment
8906	GSDS Standard Modules, General Requirements for

B. DOCUMENTS (Jet Propulsion Laboratory)

The following documents provide general information concerning the DSIF system characteristics:

TM No. 33-26	Deep Space Net System Specification, Volume 1
TM No. 33-26	Deep Space Net System Specification, Volume 2
TM No. 33-26	Deep Space Net System Specification, Volume 3

SECTION X

SPARES AND STANDARDS PHILOSOPHY

A spares philosophy has been developed to assure that the operational requirements of the DSIF are met. The criteria for quantities and types of spares required by DSIF stations follow:

1. General

Spares shall be provided so that rapid repairs may be made without the use of soldering irons or disassembly of the operating equipment. The quantity of spares supplied should be commensurate with the expected operating period of the equipment.

2. Assembly Spares

A complete replacement spare is desired for each operating assembly. An assembly is defined as a physical entity (consisting of subassemblies and interconnecting wiring) which can easily be replaced by the removal of externally mounted connectors and which is suitable for mounting in an equipment housing.

3. Subassembly Spares

In certain cases where the assemblies have been unitized; and cost, scheduling or other valid reasons prohibit acquiring assembly spares, subassembly or card spares may be supplied according to the following minimum formulae:

less than 4	identical units	-	100% spares
4 to 10	identical units	-	4 each spares
11 to 50	identical units	-	5 each spares
50 or more	identical units	-	10% spares

4. In any case, when equipment is supplied to the DSIF, it is mandatory that at least one spare for each different item must be supplied, including interconnecting cables but not including racks and associated mounting hardware.

Any deviation from the above spares requirements must be approved by written authorization from the DSIF Program Office.

APPENDIX A

An illustrative design for an Apollo TV system operating from the lunar surface to the DSIF is given in Table A-1. Using 25 watts of RF power at 1705 mc/s, from a single sideband AM transmitter, a 4-foot spacecraft antenna and the proposed 200-250 foot DSIF antenna with a low noise receiver, it is possible to obtain pictures approaching broadcast quality having 525 x 525 lines, 30 frames/second and a signal to noise ratio of 34.5 db (see Table A-2). By occupying more than the illustrated 5 mc/s RF bandwidth and employing wideband FM techniques, it may be possible to increase the 34.5 db video signal to noise ratio by another 5 db to 10 db. In either event, real time television from the Moon via the DSIF appears to be quite feasible if desired by the Apollo Project.

Table A-1. Illustrative Design for Apollo TV from the Lunar Surface via the DSIF

No.	Parameter	Value	Tolerance
1	Total transmitter power (25 watts)	+44.0 dbm	±1.0 db
2	Spacecraft transmission circuit loss	-1.5 db	±0.5 db
3	Spacecraft antenna gain (4-ft dia paraboloid)	+24.2 db	±0.5 db
4	Spacecraft antenna pointing loss	-1.0 db	±0.5 db
5	Space loss at 1705 mc/s and 4.07×10^5 km	-209.3 db	-
6	Ground antenna gain (225 ±25 ft dia)	+59.3 db	±1.0 db
7	Ground transmission circuit loss	-0.1 db	-
8	Net circuit loss	-128.4 db	±2.5 db
9	Total received signal power	-84.4 dbm	±3.5 db
10	Receiver noise spectral density	-177.9 dbm	±1.0 db
	$T_{ant} + T_{loss} + T_{receiver} = 21^{\circ}K$		
	$T_{moon} = 98^{\circ} \pm 20^{\circ}K$		
11	RF signal to noise ratio in a 5 mc/s RF bandwidth	+26.5 db	±4.5 db

Table A- 2. Video Parameters of an Illustrative Apollo TV System Employing SSB AM Transmission from the Lunar Surface to the DSIF

Video Parameter	Value
Resolution	525 x 525 lines
Frame rate	30 frames/sec
3 db video bandwidth (including sync and sound)	5 mc/s
Video signal/noise ratio (peak to peak signal/rms noise)	34.5 db

APPENDIX B

THE JPL TELECOMMUNICATION DESIGN CONTROL TECHNIQUE

1. General

The Jet Propulsion Laboratory has developed a technique for evaluating the design performance of proposed deep space communications systems. The technique has proven to be a useful management tool as well as an aid to the individual designer in detecting potential weak spots in the design. Information concerning this technique and a typical example thereof are included in this document for the purpose of ensuring better deep space communications systems.

2. Analytical Breakdown

The technique first breaks down the communications analysis into a number of sub-analyses — one for each communications mode over the entire spacecraft trajectory. A representative breakdown is shown in Table B-1. Separate design control charts, Table B-2, are then prepared for each of boxes marked "X" in Table B-1, and their respective performance margins noted. When desired, the individual performance margins may be plotted as a function of distance along the spacecraft trajectory. In this manner the relative reliability of the various communications circuits may be assessed and weak circuits detected prior to final acceptance of the over-all communications system design.

3. Preparation of Individual Communications Circuit Analyses

To be successful, the technique requires that each of the individual circuit analyses be thoroughly and accurately prepared. Every possible gain or loss along the circuit path must be accurately evaluated and a realistic tolerance applied to the nominal value (see Table B-2). To ensure that such is the case, the cognizant individual is asked to sign his name after the value used and thereafter be responsible for achieving that performance.

4. Performance Criteria

At the conclusion of each circuit analysis the positive and negative (adverse) tolerances are totaled by simple addition. The JPL criteria for a satisfactory communications channel is that the Performance Margin in the "Value" column of Table B-2 must equal or exceed the cumulative negative tolerances in the "Tolerance" column.

Table B-1. Representative Breakdown of Communications System Analysis

DSIF Station	Spacecraft Antenna & Orientation	Spacecraft Transmitter Power Level	Communications Circuit Performance Margin											
			R.F. Carrier	TV	IRIG Telemetry Ch.									
					1	2	3	4	5	6	7	8	spec.	voice
MTS	Low Gain	Low	X	X	X	X	X	X	X	X	X	X	X	X
		High	X	X	X	X	X	X	X	X	X	X	X	X
	High Gain	Low	X	X	X	X	X	X	X	X	X	X	X	X
		High	X	X	X	X	X	X	X	X	X	X	X	X
J	Low Gain	Low	X	X	X	X	X	X	X	X	X	X	X	X
		High	X	X	X	X	X	X	X	X	X	X	X	X
	High Gain	Low	X	X	X	X	X	X	X	X	X	X	X	X
		High	X	X	X	X	X	X	X	X	X	X	X	X
W	Low Gain	Low	X	X	X	X	X	X	X	X	X	X	X	X
		High	X	X	X	X	X	X	X	X	X	X	X	X
	High Gain	Low	X	X	X	X	X	X	X	X	X	X	X	X
		High	X	X	X	X	X	X	X	X	X	X	X	X
GS	Low Gain	Low	X	X	X	X	X	X	X	X	X	X	X	X
		High	X	X	X	X	X	X	X	X	X	X	X	X
	High Gain	Low	X	X	X	X	X	X	X	X	X	X	X	X
		High	X	X	X	X	X	X	X	X	X	X	X	X

Table B-2. Telecommunication Design Control Chart[a]

PROJECT: Ranger 1,2
CHANNEL: Spacecraft to MTS
MODE: Transponder Low Gain Circuit (Non Oriented)

NO.	PARAMETER	VALUE	TOLERANCE	SOURCE
1	Total Transmitter Power	34.7 dbm	±0.8 db	Randolph
2	S/C Transmission Circuit Loss	-10.78 db	±0.33 db	P. Cramer L. Randolph
3	S/C Antenna Gain	-8.54 db	+9.64, -1.82 db	P. Cramer
4	S/C Antenna Pointing Loss	(included in 3)		
5	Space Loss	-172.08 db	-	
	@ 960 MC, R = 10^{+4} KM	–		
6	Polarization Loss (A.R. = +0.6 ±0.3 db	(included in 7)	±0.5 db	D. Vincent
7	Ground Antenna Gain	22.8 db	±0.4 db	D. Vincent
8	Ground Transmission Circuit Loss	-0.80 db	±0.2 db	
9	Net Circuit Loss	-169.40 db	+11.07, -3.25 db	
10	Total Received Power	-134.70 dbm	+11.87, -4.05 db	
11	Receiver Noise Spectral Density	-168.08 db/cps	±0.5 db	
	T system =	1130° K	+137, -124° K	D. Vincent
12	Carrier Modulation Loss	-3.89 db	+1.57, -1.69 db	L. Randolph R. Harker
13	Received Carrier Power	-138.55	+13.44, -5.74 db	
14	Carrier APC Noise BW ($2B_{LO}$ = 20 ±4 cps)	13.01 db/cps	+0.79, -0.97 db	D. Vincent
	CARRIER PERFORMANCE - TRACKING (one-way)			
15	Threshold SNR in $2B_L$	0.0 db	-	
16	Threshold Carrier Power	-155.07 dbm	+1.29, -1.47 db	
17	Performance Margin	16.48 db	+14.91, -7.03 db	
	CARRIER PERFORMANCE - TRACKING (two-way)			
18	Threshold SNR in $2B_L$	1.0 db	-	
19	Threshold Carrier Power	-154.07 dbm	+1.29, -1.47 db	
20	Performance Margin	15.48 db	+14.91, -7.03 db	

IPL 0438 APR 61

[a] The illustrative example given in this table contains the actual numbers for Ranger 1 and 2 as viewed from the Mobile Tracking Station deployed at Johannesburg, South Africa. The data are for the main RF carrier via the low-gain antenna at a spacecraft range of 10,000 KM.